

The impact of free access to the scientific literature: a review of recent research

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Objectives: The paper reviews recent studies that evaluate the impact of free access (open access) on the behavior of scientists as authors, readers, and citers in developed and developing nations. It also examines the extent to which the biomedical literature is used by the general public.

Method: The paper is a critical review of the literature, with systematic description of key studies.

Results: Researchers report that their access to the scientific literature is generally good and improving. For authors, the access status of a journal is not an important consideration when deciding where to publish. There is clear evidence that free access

increases the number of article downloads, although its impact on article citations is not clear. Recent studies indicate that large citation advantages are simply artifacts of the failure to adequately control for confounding variables. The effect of free access on the general public's use of the primary medical literature has not been thoroughly evaluated.

Conclusions: Recent studies provide little evidence to support the idea that there is a crisis in access to the scholarly literature. Further research is needed to investigate whether free access is making a difference in non-research contexts and to better understand the dissemination of scientific literature through peer-to-peer networks and other informal mechanisms.

INTRODUCTION

A principal argument in support of open access publishing rests on the belief that the subscription-based publishing model has produced a crisis of accessibility to the scientific literature [1–6]. This paper evaluates that claim, reviewing the current literature and showing the ways in which free access has (or has not) had an impact on scholars, clinicians, and the general public in developed and developing nations.

The review assesses impact in terms of reading, citation, and related forms of use. It does not evaluate the extent to which the freely available scientific literature is technically accessible, indexed, cataloged, or available for *potential* use. The discussion deals only with the scholarly literature, thereby excluding studies of online newspapers, magazines, and trade publications. It also focuses on the natural sciences, since most of the research on free access has dealt with fields such as the biomedical, physical, and computer sciences. Although “open access” is the usual term for scholarly work that is freely accessible online, the term “free access” is used here, since open access is often understood to include issues of copyright, archiving, funding, and social justice that are not addressed in this discussion.

The paper first reviews the impact of free access on the research practices of scholars in developed and developing nations, then examines the use of freely available biomedical literature by health professionals and the lay public. It concludes with a discussion of avenues for further research.

Highlights

- Researchers in the sciences do not see access to the scientific literature as an especially important problem.
- Authors consider factors such as journal reputation and the absence of publication fees when deciding where to submit their work. In contrast, free access is not a significant factor in their submission decisions.

Implications

- While open access has the potential to expand the authorship and readership of the scientific literature, that potential has not yet been realized.
- Librarians who encourage scientists to publish in open access journals should be aware of the authors' priorities and perspectives. Authors in the sciences tend to focus on citation impact, reputation, and accessibility to a specialized readership—not breadth of readership, copyright, or access status.
- Journal publishers that charge publication fees may want to consider alternative sources of revenue. Authors' resistance to publication fees is a major barrier to greater participation in open access initiatives.

METHODS

The analysis is based on a review of current empirical studies (January 2001 through December 2010) that attempt to measure—directly or indirectly—access to and use of the scientific literature by academics, clinicians, and the lay public. Relevant works were identified from several sources: bibliographic data-



Supplemental Tables 1 and 2 are available with the online version of this journal.

bases, cited references, personal correspondence, and prior experience with the topic. Studies of how information is produced, published, and made publicly available, such as papers on the economics of scientific publishing, are excluded. Also excluded are works that rely solely on personal convictions and anecdotal evidence, as well as those that report redundant findings (such as conference presentations, posters, and summary reports).

APPROACHES TO STUDYING SCHOLARS' USE OF THE SCIENTIFIC LITERATURE

Current research on the use of the scientific literature follows two main methodological approaches. The first makes use of surveys and interviews to examine scholars' perceptions and opinions of the scholarly communication system. The second relies on bibliometric evidence—on unobtrusive studies of what scientists download, read, and cite.

Each approach has both strengths and weaknesses. Surveys can be used to elicit the responses of thousands of individuals in order to draw conclusions about a target population. In-depth interviews, while limited in their generalizability, can be used to explore a topic in detail and to examine the values and motivations of interview participants. Nonetheless, poorly constructed or poorly executed surveys and interviews are susceptible to many forms of bias, including sampling bias (the inability to reach a representative target audience); nonresponse bias (the underrepresentation of particular subgroups in the sample); response bias (bias associated with the survey instrument itself—the framing, formulation, and ordering of survey questions, for example); acquiescence bias (the tendency for respondents, when in doubt, to respond in the affirmative); and social desirability bias (the tendency for respondents to provide a response they believe to be socially supportive), among others [7, 8]. Many of the studies described in this review suffer from one or more forms of bias.

Unobtrusive methods, such as counting article downloads or citations, offer a more direct approach to measuring what scientists *actually do*, rather than what they say they do. While these methods avoid the potential biases of survey and interview research, many forms of unobtrusive methods are susceptible to limitations of their own, the most common of which is interpretive. Downloads are often equated with reading, for example, yet this connection is purely inferential. Devoid of context, a download statistic does not reveal who was responsible for the download (or whether the agent was even human), why the article was downloaded, or how the article was used (if it was used at all). Moreover, download statistics can vary substantially based on the characteristics of the user interface [9]. Last, a citation implies—but does not require—that the document has been accessed and read. Because an author may cite from the abstract of an article or simply copy a reference from another paper [10, 11], citation data may

overstate the extent to which the scientific literature has been consulted.

In evaluating scholars' use of the research literature, it is important to acknowledge the limits of what each study can add to knowledge of the issues. As most scientists are both readers and authors, their interests and priorities may vary with the role they assume at any particular time [12].

AUTHORSHIP AND USE OF THE SCIENTIFIC LITERATURE BY SCHOLARS IN DEVELOPED NATIONS

Studies based on surveys and interviews

Over the past thirty years, periodic studies of the information-seeking and reading behavior of scientists in the United States have revealed three trends: (1) scientists are reading more articles while spending less time searching and retrieving them; (2) scientists now read from a broader group of journals and extend their reading into the older literature; and (3) scientists have become more reliant on institutional (library) access to journal collections, although they also make use of informal sources such as preprint servers and colleagues [13–21].

Overall, most surveyed researchers indicate that they have adequate access to the scientific literature and that access conditions are generally improving. An international survey of authors conducted in 2004 revealed that 61% of respondents indicated that they had “good” or “excellent” access to the journal literature. Three-quarters (76%) of respondents also felt that access was easier than it was 5 years ago [22]. A similar study of immunologists and microbiologists conducted in 2004 revealed that two-thirds of respondents (67%) reported they had “good” or “excellent” access to the literature [23]. Nearly 84% claimed that access was much better now than it had been 5 years before, and almost all (97%) reported that they were “very up-to-date with the current literature in their area,” with less than 35% reporting any need for greater access to the research literature. In a list of 16 potential barriers to higher research productivity, journal access ranked 12th, below everything but greater conference/networking opportunities, better research leadership, more general management training, and clearer legal and ethical frameworks [23].

Surveying international scientific authors in 2007, Ware found that 69% of respondents reported having “good” or “excellent” access to the literature, a figure that varied by region [24]. Authors in the United States and Canada were most satisfied (85% reported “good” or “excellent” access; 3% reported “poor” access), while those in other countries were significantly less satisfied (53% reported “good” or “excellent”; 15% reported “poor”). In Ware's latest study, conducted in 2010 [25], 93% of all respondents reported having “very easy” or “fairly easy” access to the journal literature, a finding which varied from 97% for North American respondents to as low as 78% for African respondents.

Ware also surveyed small and medium-sized commercial enterprises in the United Kingdom, including companies involved in pharmaceuticals, chemicals, computing, and medical and precision instruments [26]. More than 70% of respondents claimed that they had “very easy” or “fairly easy” access to the journal literature, and 60% reported that their level of access had gotten better over the past 5 years. Among enterprises with more than 250 employees, 82% reported having easy access to the journal literature. Ware’s study used a sample of convenience, however, and only 4% of potential respondents completed the survey.

While greater access to the scientific literature has undoubtedly altered the behavior of scientists as *readers*, it is not among their main priorities as *authors*. In deciding where to submit their work, an international survey of scientists revealed that authors were most concerned with each journal’s reputation, readership, impact factor, and speed of publication [27]. In contrast, access status and copyright-related issues were ranked last.

Although these large-scale studies are prone to several forms of bias, such as sampling bias and nonresponse bias, they are confirmed by a number of smaller but more rigorous studies of authors’ preferences. For example, authors submitting manuscripts to the *British Medical Journal* reported that impact factor, reputation, readership, speed of publication, and quality of peer review were all major factors in deciding where to submit their work. In contrast, only 13% rated free access as important [28].

In-depth interviews with authors and other stakeholders reveal similar values and priorities. A series of interviews with faculty at the University of California, Berkeley, revealed that authors were most concerned about the mechanisms that ensure the quality of journal articles and the integrity of the peer-review process. Other considerations, such as the costs of the scholarly publication system, did not have much impact on their work [29]. Although many librarians “strongly perceive a crisis in scholarly communication,” most faculty do not, underscoring a fundamental perceptual difference between these two stakeholder groups.

A recent and more extensive study, by Harley and colleagues, explored the values, motivations, and behavior of 160 interviewees at 45 research universities across the United States [30]. The recurring theme in this report is that the scholarly community is conservative, with a firm dedication to disciplinary norms and an unyielding commitment to external peer-review and assessment. There is little room for experimentation with new forms of publication, especially for new academics. In particular, many faculty view author-pays open access publishing with suspicion due to the potential conflict between publication fees and rigorous peer-review. Overall, Harley and colleagues “heard little about a crisis in scholarly communication” [30]. The only faculty who perceived a crisis were some of those in the humanities, who noted that the diminishing output of university presses made it more difficult to publish their work as academic books.

Several months after the Harley report, Schonfeld and Housewright released another report on the perceptions and behavior of faculty with regard to scholarly communication [31]. Their findings, based on a series of longitudinal surveys conducted every three years since 2000, were remarkably consistent with those of the Harley report. With regard to publishing, faculty attitudes are fundamentally conservative and are guided almost entirely by career advancement. Faculty expressed little interest in transforming the scholarly communication system, and across all disciplines, free access to journal content was consistently ranked last among the factors considered by authors when selecting a journal in which to publish. In contrast, the absence of publication fees was ranked as the second most important factor, suggesting, as Schonfeld and Housewright [31] pointed out, that the author-pays model of open access publishing might be at odds with the attitudes of many faculty. As numerous studies have shown, the primary goal of most faculty is to publish in journals that are widely read by scholars in their field [23, 27, 28, 32]. If transforming the scholarly publishing system is a goal of faculty, that goal is nonetheless eclipsed by issues of career advancement.

Table 1 (online only) presents a summary of the major studies described in this section.

Studies based on unobtrusive methods

Downloads. Usage data compiled from the online transaction logs of Elsevier and Oxford University Press reveal two major trends of the past several years: an increase in the number of journals available at a typical university and an even larger increase in the number of article downloads [33]. Publishers who offer package deals view these data as an indication that they are providing increasing value to the academic community [34]. While these trends suggest the importance of commercial access to the scientific literature, little is known about the effect of free access on readership.

A case study of article downloads for the journal *Nucleic Acid Research* revealed that moving from a subscription-access model to an open access model resulted in more than twice the number of article downloads (portable document format [PDF] and hypertext markup language [HTML] combined), although most of this increase was attributed to Internet robots (automated applications that index web pages) rather than human intention [35]. Likewise, randomized controlled trials of open access publishing revealed that free access has a significant, independent impact on the number of downloads, although robots account for roughly half of the increase [36]. Articles that were made freely available received about twice as many full-text downloads but correspondingly fewer PDF downloads, suggesting that the primary benefit to the non-subscriber community is in browsing [36–38]. Due to the nature of these studies, which rely on transactional usage logs, it is only possible to make inferential statements

about reader behavior. Further investigation is required to determine who is accessing these articles and for what purpose.

Citations. The impact of online and open access on scholars' citation behavior is not entirely clear. There is some dispute over whether increased access has broadened the scope of cited material. Using a complex inferential model, Evans [39] reported that commercial access to the literature through large online collections and full-text databases has led to a reduction in the scope of the articles that are likely to be cited, with an emphasis on newer articles from a smaller number of journals. McCabe and Snyder refuted these claims, asserting that Evans' model suffered from a methodological flaw [40]. Moreover, Larivière and colleagues [41] reached a different conclusion: that citations to the scientific literature are becoming *more* dispersed over time. Their findings are supported by a number of author surveys [13–21].

Several studies have indicated that free (or open) access to scientific publications leads to significant increases in the number of article citations [42–51]. These studies imply that the demand for access to the scientific literature has not been fully met by current distribution models. Other studies claim that free access is responsible for accelerating the citation process [52–57] or that it may have preferential effects for researchers in developing countries [58, 59].

Most studies investigating the association between access status and citations are based on various forms of unobtrusive, observational analysis. As Craig and colleagues [60] illustrate in their comprehensive review of the literature, many of these studies suffer from three methodological problems: (1) failure to control for confounding variables (i.e., failure to distinguish clearly between the impact of access status and the effects of related variables); (2) failure to provide more than correlation as evidence of a causal relationship; and (3) inadequate specification of the observation window for the citation process. As a number of critical studies have shown, these issues make it difficult to determine whether free access has a real, independent effect on citation rates [36, 54–57, 60–66]. McCabe and Snyder argue that the large citation effects reported in prior studies are simply artifacts of the researchers' inability to control for important covariates such as time and differences in article quality [40].

To isolate the effect of free access on article readership and citations, Davis and colleagues conducted several controlled experiments that allowed them to randomly assign free-access status to articles on the websites of various academic journals. In theory, random assignment allows the researchers to control for potential differences at the start of the experiment, including unobserved variables such as article quality, between the treatment and control group. In their first study, involving eleven journals in physiology, they found that open access articles received more article downloads, yet no more

citations than subscription articles in the first year after publication [36]. A larger trial involving thirty-six journals in the sciences, social sciences, and humanities demonstrated no citation difference at three years [37, 38].

Overall, the conclusions of Craig and colleagues [60] are well supported by subsequent work. After controlling statistically or methodologically for confounding effects, there is little evidence that open access status has an independent effect on citation counts. Table 2 (online only) presents a summary of the key papers that examine the impact of free access on citation rates.

AUTHORSHIP AND USE OF THE SCIENTIFIC LITERATURE BY SCHOLARS IN DEVELOPING NATIONS

The high cost of Western scientific journals poses a major barrier to researchers in developing nations. While researchers in North America and Western Europe rely primarily on institutional (library) access to scholarly journals, the situation is different in many developing nations. Researchers in India, for example, rely more heavily on informal access to the scientific literature because their institutions are unable to provide the research literature they require [59].

Collaborative projects such as HighWire's Free Access to Developing Economies [67] and multi-publisher programs focusing on disciplines such as agriculture (Access to Global Online Research in Agriculture [AGORA]), health and medicine (Health InterNetwork Access to Research Initiative [HINARI]), and the environment (Online Access to Research in the Environment [OARE]) have attempted to bridge the access gap by providing free or heavily subsidized access to institutions in the world's poorest regions [68]. Several studies have attempted to ascertain whether researchers in developing countries have benefited from free access by determining whether free access has influenced their authorship and citation behavior. In her dissertation, Ross [69] evaluated the effectiveness of the HINARI and AGORA programs by analyzing the citations to participating journals before and after the programs were initiated. Her results were mixed: In some regions, citations to the participating journals increased, while in others, they decreased. No systematic geographical pattern was reported.

An analysis of open access and subscription journals in the field of biology revealed that authors in developing countries are no more likely than authors in developed countries to cite or to publish in open access journals [70]. Likewise, a study of conservation biology journals and book chapters revealed that authors in developing countries do not cite freely available articles at a higher rate than articles requiring subscriptions [64]. Both these studies were based on small samples with high variability, so they might not have the statistical power to detect small effects. However, the absence of strong effects in both these studies suggests that the impact of free access on

developing-country publishing or citation patterns, if it indeed exists, is likely to be small.

A larger, comparative study of Swiss and Indian scholars revealed that articles written by Indian researchers had shorter reference lists and were more likely to cite articles from open access journals [59]. The effect sizes reported by Gaulé were small, though. Controlling for the publication source, Indian reference lists were 6% (less than 2 references) shorter and contained just 0.16 more citations to open access articles. Considering that Indian research institutions have far poorer access to the published literature than their Swiss counterparts, the impact of free access appears to be modest. Supplementing his bibliometric analysis with a follow-up survey, Gaulé [59] found that Indian scholars routinely requested copies of articles from the authors of the studies and from their colleagues at better-endowed institutions. Some respondents admitted asking former students who had moved to North American or European institutions for help with access to the journal literature.

On a global scale, Evans and Reimer [58] reported that free access to the published literature had a small but significant effect on citation behavior, especially for authors in developing nations. However, McCabe and Snyder concluded that the apparent geographical differences in citation rates were an artifact of the methods Evans and Reimer used. Using a similar dataset, McCabe and Snyder found no regional differences in citation rates [40]. While the developing world benefits from online access to the scientific literature, McCabe and Snyder report, that gain is no greater than the benefit derived by scholars in the United States and other English-speaking Western countries.

The greatest reported impact of free online access was mentioned in a press release from Research4Life [71]. The authors claimed that the total annual output of peer-reviewed research articles increased substantially among countries that participated in the HINARI, AGORA, and OARE programs. Unfortunately, the press release did not provide information on the methods used to reach that conclusion, and no attempt was made to control for potentially important confounding factors, such as country wealth, national expenditures on research and development, number of active scientists, emergence of research centers in high-impact fields such as medicine, or improvements in library and information technology infrastructures. The authors also provided no data on the number of articles published in each country, as even modest increases in article publication in countries with historically low output can result in high percentage increases. In the absence of more detailed information, the Research4Life results should be considered speculative at this point.

IMPACT OF FREE ACCESS ON CLINICAL DECISION MAKING

To date, only one study has evaluated the clinical implications of free access to the medical literature. In

a pair of related experiments, Hardisty and Haaga [72] investigated whether increased access to relevant journal articles had an impact on the use of the articles in clinical psychotherapy. Participating mental health professionals were provided with 1 of 4 access conditions: (1) no mention of the relevant article, (2) a citation to the article without a hyperlink, (3) a citation with a link to the article (which cost \$11.95 for all but registered subscribers), or (4) a citation with a link to a free copy of the article. After 1 week, participants read a vignette on the topic covered by the article and were asked about their recommendations for a medical intervention. In both studies, participants in group 4 were most likely to report having read the article. However, in only 1 study did reading the article translate into making a recommendation consistent with the information it presented. These results indicate that while free access increases the likelihood of downloading and reading research articles, it does not necessarily influence clinical practice. Further research is necessary, however, because Hardisty and Haaga's study represents just one clinical setting and one of several possible evaluation methods.

USE OF THE BIOMEDICAL LITERATURE BY THE GENERAL PUBLIC

The empowerment of health care consumers through universal access to original research has been cited as a key benefit of free access to the scientific literature [73]. However, relatively little is known about the use of scientific literature by the general public. Anecdotal descriptions are not uncommon—for instance, patients bringing medical literature they found online into the doctor's office—but relatively few studies have investigated how the public uses the primary research literature rather than consumer-focused websites, blogs, and discussion lists.

It is clear, however, that Americans are actively seeking health information online. Periodic telephone surveys of American adults conducted by the Pew Research Center reveal that the percentage of adults who look for health information online increased substantially between 2002 and 2008 [74]. By 2006, 80% of American Internet users had searched for information on at least 1 health-related topic [75]. That figure, unchanged in 2010, varies with income, race, and other demographic and socioeconomic characteristics [76]. For those with a disability or chronic disease, the percentage is even higher, about 86% [77]. Those with chronic conditions are also especially likely to report that online searching has affected their treatment decisions and their interactions with doctors. Respondents who experienced recent health crises are also more likely to get a second opinion or to ask their doctor new questions based on their online research, and, not surprisingly, individuals with home broadband access are more than twice as likely as dial-up users to conduct health research online [78]. According to the Pew telephone surveys, most Internet users begin their research on health or

medical topics by using a general search engine such as Google rather than a health-related website [75]. These results are confirmed by naturalistic observational studies of how laypersons search for online health information in an experimental setting [79–81].

Distinguishing primary literature from secondary and user-generated sources

The Pew telephone surveys list many sources of medical information including websites, blogs, commentary, and podcasts, but they do not ask respondents to distinguish between scholarly and non-scholarly resources [74, 82]. In particular, they make no specific mention of journals or scientific articles as sources of medical information, although they do distinguish “Internet” from “printed reference material” [82], as well as identifying cell phones and mobile applications [83]. Likewise, the Health Information National Trends Survey (HINTS) of the National Cancer Institute asks several questions about sources of health information, but the available responses represent a potentially confusing set of information providers, media, and delivery mechanisms [84]. For example, question HC02 asks, “The most recent time you looked for information about health or medical topics, where did you go first?” and offers response categories such as “Internet” (61.0%); “Doctor or health care provider” (13.9%); “Books” (8.4%); “Brochures, pamphlets, etc.” (3.8%); and “Magazines” (3.4%). It is difficult to discern what the researcher is implying—or, indeed, what the survey respondent might be thinking—when asked about Internet use. Magazines, books, brochures, and health care providers can all be accessed via the Internet, just as doctors and other health care providers communicate in person, via the Internet, and through books, brochures, and magazines. A more recent (2010) survey of the health-seeking behavior of adults separated “Internet” from “Media,” the latter consisting of newspapers, magazines, and television [85]. Neither of these studies distinguished between the primary medical literature (e.g., scholarly journals) and popular health magazines.

Most medical and health-related websites suffer from significant problems in terms of accuracy, bias, and completeness [86, 87]. Nongovernmental websites are especially prone to these problems [88]. While laypersons claim that they use a number of criteria in evaluating the credibility of medical websites, few of them actually check the authority of web resources or are able to later recall the sources of their information [79]. Indeed, just 15% of telephone survey respondents claimed that they “always” checked the source and date of the information they found online, and 10% claimed that they did so “most of the time” [89].

Evaluating websites retrieved through a series of online searches for medical terms, Laurent and colleagues found that the user-generated online encyclopedia, Wikipedia, ranked higher in the search results than professional sites such as MedlinePlus, which is maintained by the National Library of

Medicine and the National Institutes of Health [90]. Indeed, Wikipedia appeared on the first page, among the first ten results, for the overwhelming majority of medical keyword searches conducted in Google, Google UK, Yahoo, and MSN. Despite significant errors of omission and the absence of source attribution [87], Wikipedia is a prominent source of online health information.

No study has systematically evaluated the extent to which the general public makes use of the primary medical literature rather than secondary and user-generated sources such as Wikipedia and WebMD. Nonetheless, the available evidence shows that “the Internet” (however survey respondents might define it) is the primary source of health-related information for the American public and that typical Internet users are far more likely to encounter secondary sources of health information than the primary health sciences literature. Research has shown that the quality of consumer health information can be improved through better integration of the primary literature into online health resources and through public involvement in the development of such resources. However, even these efforts involve the use of tools and interfaces that repackage, summarize, and simplify the results of medical research—not on the unmediated reading of the scientific literature by the general public [91–93]. Overall, the published evidence does not indicate how (or whether) free access to the scientific literature influences consumers’ reading or behavior.

SUMMARY AND DISCUSSION

Access to the scientific literature is not a serious concern of most scholars in developed nations, and most researchers feel that their access to the literature is steadily improving. While free access leads to greater readership, its overall impact on citations is still under investigation. The large access-citation effects found in many early studies appear to be artifacts of improper analysis and not the result of a causal relationship.

Current research reveals no evidence of unmet demand for the primary medical or health sciences literature among the general public. This does not necessarily reflect the absence of unmet demand; it may simply indicate that the question has not been addressed adequately. Likewise, almost no studies have evaluated whether free access to the scientific literature has had an impact on the use of scientific information in non-research contexts such as teaching, medical practice, industry, and government.

Sources of bias in the research literature

Most studies on the use of the primary scientific literature reflect the opinions and behaviors of those who are well integrated into the system of scholarly communication. This might be regarded as a form of bias because the true population of interest includes not just those who currently rely on the research

literature, but those who might make good use of it if they were more fully aware of its utility. Arguably, the greatest value of open access journals and archives is their potential to make scholarly information available to those who consume, but do not contribute to, the scientific literature. At present, however, there is little evidence that this potential has been realized. Admittedly, the existence of a resource (such as a library collection or a body of open access literature) has value independent of the number of downloads, citations, or other indicators of use: option value (the value of the personal right to use the resource in the future), existence value (the value derived from the knowledge that the resource is available for others' use), and bequest value (the value of making the resource available to future generations of scholars) [94]. However, these kinds of utility are difficult to measure; are not as readily apparent to authors, readers, and publishers; and are of less immediate value than the indicators of use that drive the present-day scholarly communication system.

Impediments to broader access

The studies presented here suggest that publication fees are perhaps the greatest impediment to broader participation in open access initiatives. While fewer than 30% of open access journals charge publication fees, those journals represent half of all open access articles [95]. Moreover, the proportion is much higher for particular disciplines and publisher types. For example, publication fees were levied for approximately 69% of the open access biology articles published in 2008/09 (all publisher types combined) and for 76% of the commercially published open access articles in 6 subject areas [95]. At the same time, there is clear evidence that faculty generally do not like publication fees [31], and many fear that the pay-to-publish model may compromise the integrity of peer review [30]. It is important to realize that individuals' opinions of general publishing practices may be contrary to their attitudes about particular journals. For instance, *PLoS Biology* and *PLoS Medicine* both charge relatively high publication fees, but neither seems to have trouble attracting submissions. The business model adopted by these 2 journals may or may not be transferable to other journals or publishers, but it does demonstrate that at least some free-access journals have the potential to transcend the limitations noted here.

Alternative routes of access to the scientific literature

Most research on access to the scientific literature assumes a traditional and hierarchical flow of information from the publisher to the reader, with the library often serving as an intermediary between the two. Very little has been done to investigate alternative routes of access to the scientific literature. If consumers of the scientific literature operate in the same way as consumers of cultural media (music and video, for example), studies that focus on publisher-

initiated communication might overlook important components of the scholarly communication system. While interlibrary lending is one such component, the direct transfer of documents among colleagues may represent an even larger flow of information. Gaulé's [59] study of access to scientific information in India suggests that informal peer-to-peer sharing is very common in countries with a history of poor access to the scientific literature. For authors, the practice of fulfilling reprint requests by physical post has largely been replaced by transmitting articles by email or by directing readers to publicly accessible online archives or the public Internet [96].

A 2009 mandate of the US National Institutes of Health requires researchers in receipt of federal funding to deposit their final, peer-reviewed manuscripts in PubMed Central [97]. Several research universities have also set forth their own self-archiving requirements [98]. Open access archives such as PubMed Central may attenuate existing access inequalities, but only if authors' manuscripts are adequate substitutes for the published record. This requires, among other things, that manuscripts are posted online in a timely fashion, made readily discoverable by readers (through indexing or other mechanisms), and preserved for future use.

Further research

As noted earlier, there is a clear need for empirical research dealing with the impact of free access on the use of the scientific literature by the general public and by communities that consume, but do not contribute to, the scholarly literature. It is also important to gain a better understanding of the constructs and measures that are commonly used in studies of scholarly publishing. For instance, to what extent do downloads and citations correspond to the careful reading of articles?

Research on free access might also be improved through more careful attention to the various forms of bias that persist in both surveys and observational studies. For instance, studies of the impact of free access on citation rates have been hindered by a number of methodological problems including selection bias and incomplete model specification (e.g., failure to control for all relevant confounding variables). Studies of free access are likely to benefit from a greater understanding of these problems and a stronger consensus on the most effective ways of dealing with them.

Finally, further research should investigate the extent to which scholars rely on informal sharing of the scientific literature. This kind of sharing is often poorly documented, since individuals are not required to track and report document transactions to the publisher, nor are institutional repositories, subject repositories, public websites, or peer-to-peer file sharing programs. By relying entirely on publisher-provided usage data, researchers may underestimate the extent to which scholarly works are disseminated through such secondary and tertiary

pathways. It is possible that these alternate methods of access help to attenuate the current inequalities in formal access to the scholarly literature.

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